Renewable and Sustainable Energy Reviews 15 (2011) 4775–4779

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A review of drivers, benefits, and challenges in integrating renewable energy sources into electricity grid

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A R T I C L E   I N F O

Article history:
Received 2 March 2011
Received in revised form 17 April 2011
Accepted 5 July 2011
Available online 5 October 2011

Keywords:
Distributed generation
Renewable energy distributed generation
electricity network

A B S T R A C T

Since the global warming and climate change are recognized as real concerns, attention of power system planners and operators, energy policy makers and regulators as well as developers around the world including Australia is focused on using alternative and low emission energy technologies for electric power production.

Renewable energy and energy efficient technologies have many advantages including reducing climate change, increasing sustainability in power sector, and increasing security of power supply.

This paper presents an overview on both current electricity grid and future grid. Experts believe that in future more distributed generation (DG) will be integrated into the low to medium electricity grid. This paper will also review the key drivers in relation to integration of increased DG technologies in general and the renewable energy-distributed generation (RE-DG) technologies in particular, into the electric power system and the opportunities and challenges linked to these technologies. This paper also reviews possible connection location of RE-DG into the grid and its impact on system voltage.

Contents

1. Introduction

The growing awareness of the impacts of greenhouse gas emissions on global climate change has necessitated a reassessment of the current approach to achieve a more environmental, and economical, sustainable energy supply for the future. Without any doubt, the increasing utilization of alternative sources is the key to a cleaner and sustainable energy in the future.

The important aspects of energy such as security of supply; the economic sustainability; and the effect of energy production and its use on the environment are closely related and need to be carefully considered when decision on energy policy is made [1].

The concept of distributed generation system has been around for more than a decade. Unlike central power plants, in DG system the generators of different technologies (renewable or non-renewable) in smaller size but larger in numbers are constructed much closer to the loads and connected to low to medium voltage of the electricity networks. Today, RE-DG is considered in the context of the wider concept of distributed energy generation. The power system structure of the future, incorporating more RE-DG, will look very different from that of today.

There are clear evidences suggesting that RE-DG is growing worldwide and Governments around the world considering ambitious targets of incorporating considerable amounts of RE-DG in response to the climate change challenges, the need to enhance fuel diversity, increasing security of energy supply and economic sustainability. There are many factors driving usage of RE-DG. The

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doi:10.1016/j.rser.2011.07.074

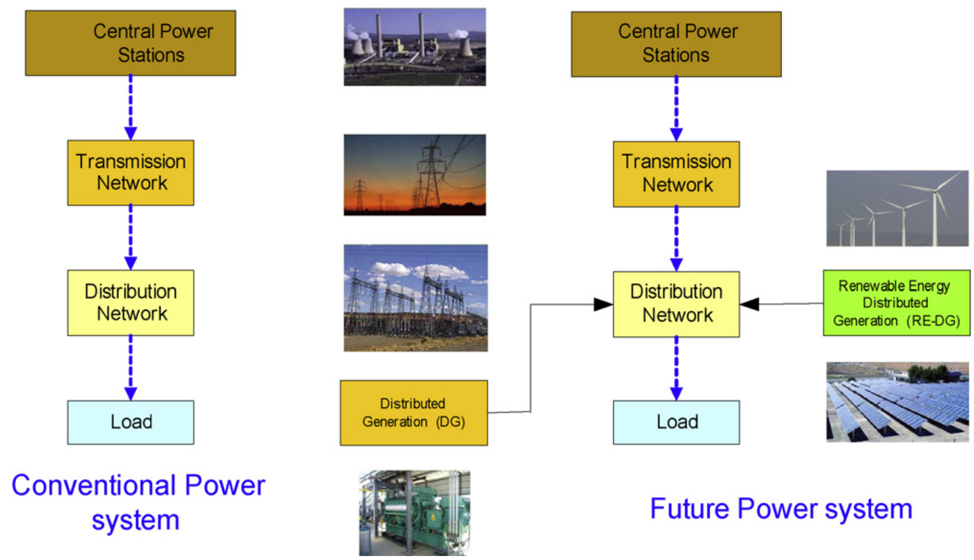

Fig. 1. Conventional and future power system.

most significant drivers for renewable energy are public perception and government, while cost is still significant barrier.

2. Potential benefits of DG systems

As the demand for more reliable and secure power system with greater power quality increases, the concept of distributed generation becomes more popular [2]. This popularity has developed simultaneously with the decrease in manufacturing costs associated with clean and alternative technologies, like fuel cells, biomass, micro-turbine, and solar cell systems. Although the costs associated with these technologies have continued to decrease, more work is needed to be done to make these technologies readily available. RE-DG is an effective way of power supply and its presence close to load can have positive impacts on power quality and supply reliability together with other environmental benefits that RE-DG have. Fig. 1 shows the conventional power system and the future power system. There will be distributed generation technologies of different types, renewable and non-renewable sources, connected to the distribution network at low to medium voltage level.

Unlike the existing large-scale electrical transmission and distribution network, distributed generation systems demonstrate higher efficiency. As customers' electricity bills include the cost of inefficient transmission grid, therefore the use of distributed generation can provide consumers with more affordable electricity.

Because of diversity of energy sources, distributed generation technologies may provide benefits in the form of more reliable electric power. Distributed generation produces power locally for the users, and then it has the potential to reduce demand during peak times and minimizing congestion of power.

Distributed generation has also the potential to contribute to deferring transmission upgrades and expansions [3]. DG technologies can provide social benefits to society by reducing greenhouse gases. Distributed generation technologies can provide emergency power for a large number of services, such as combined heat and power (CHP) for hospitals. Details of benefits of distributed generation are beyond scope of this paper, but following is a list of potential benefits of distributed generation:

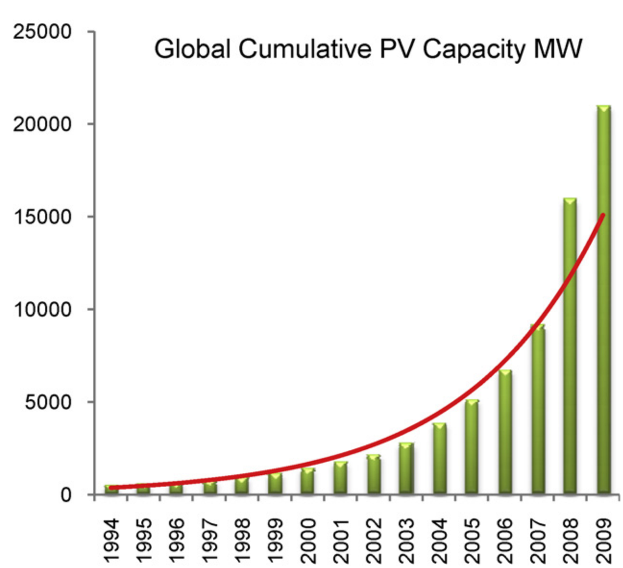

Fig. 2. Global PV energy capacity.

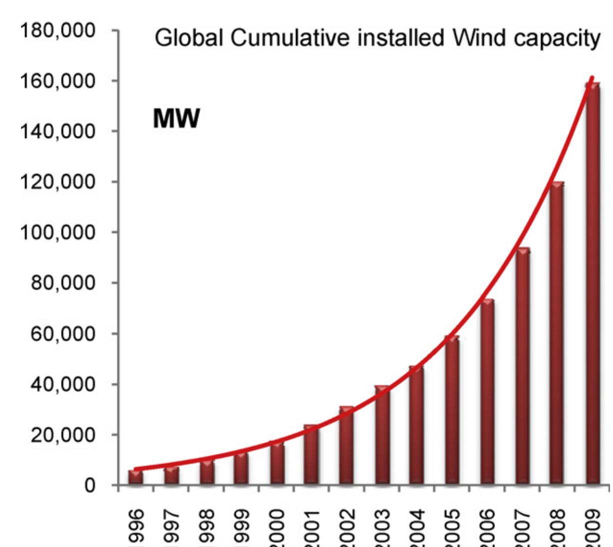

Fig. 3. Global wind power capacity.

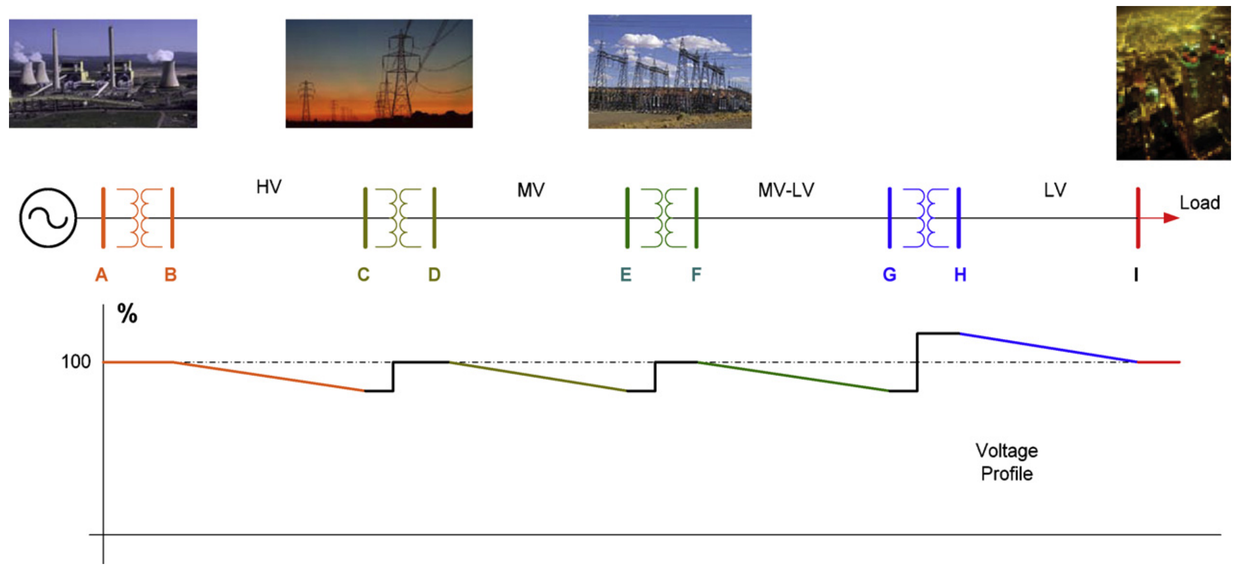

Fig. 4. A simplified power system and voltage profile.

- Energy cost savings
- Savings in power losses in the transmission and distribution networks
- Deferred new large power plants
- Deferred transmission line extension
- Increased reliability
- Enhances power quality
- Reduced land use
- Reduction in peak power requirements
- Potential use as emergency supply

3. Potential benefits of the RE-DG systems

In addition to the benefits of distribution generation mentioned above, the RE-DG using solar energy and wind power, micro-hydro, biomass, etc. offers more environmental, social, and in some cases economical benefits. The use of solar energy and wind power has increased so fast in the past two decades that these two technologies are considered as success story [4]. However, the intermittency nature is considered as weakness of these sources.

Solar energy is sustainable and widely available almost everywhere on the earth. Solar energy technologies use only ordinary materials. Solar energy uses a resource that is far larger than required to provide all of the world's energy [5]. A simple calculation shows that the amount of energy received in 1 h by the earth from the sun is equivalent to world energy consumption in one year. Unlike nuclear, solar energy has no security and military risk. Unlike oil and gas, used for conventional distributed generation technologies, solar energy is available almost everywhere. Unlike fossil fuels, solar energy has minimal environmental impacts. No increases in the cost of fuel, routine maintenance is far less than conventional plants, and the fuel (sun energy) does not have to be transported.

Wind energy conversion is a mature technology, uses free fuel. In some applications the energy production cost ($/kWh) as low as conventional power generation technologies. Environmental issues are very low; wind energy contributes to security of supply, and together with storage able to serve the base load.

Both sun energy and wind power are considered as fast growing technologies of the past two decades. Fig. 2 shows the development of the world solar photovoltaic capacity [6,7], while Fig. 3 shows development of the world wind power capacity [8].

The variable nature of power generation from intermittent sources such as solar and wind has raised concerns about the ability of providing a reliable power supply. The fact is that energy generation from renewable energy (solar and wind) is seldom constant

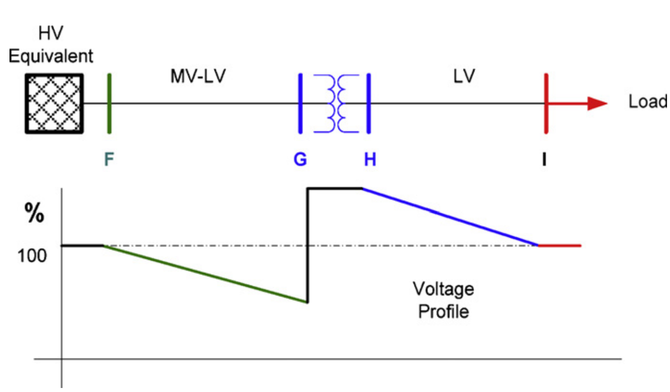

Fig. 5. Voltage profile at LV side with no RE-DG connections.

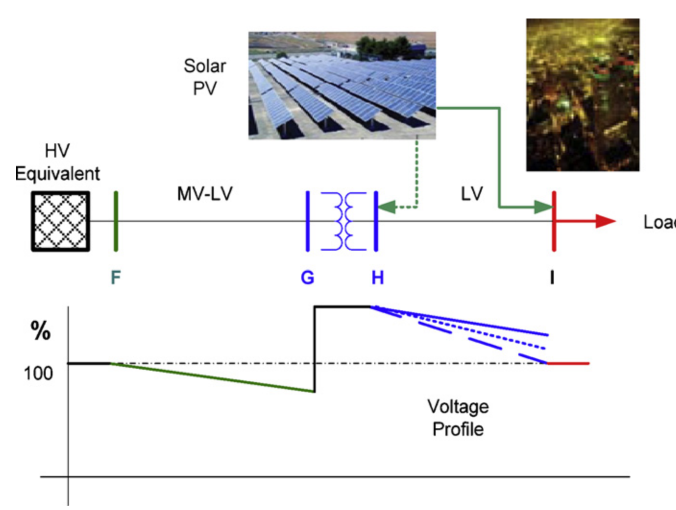

Fig. 6. Voltage profile at LV side with different RE connection points.

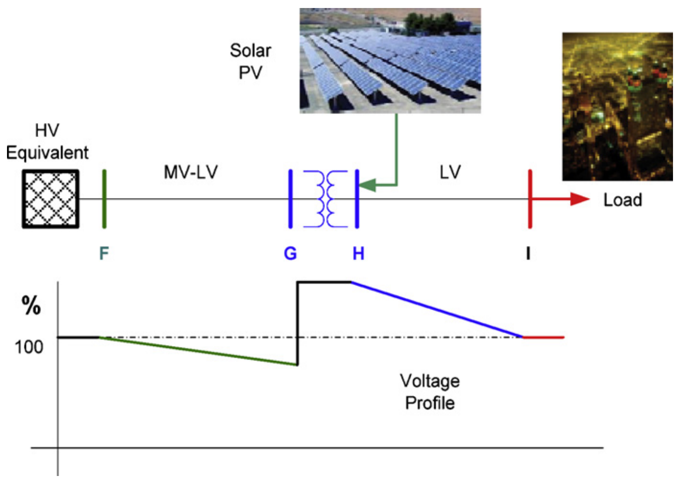

Fig. 7. Voltage profile at LV side when RE is connected at MV-LV transformer side.

over time and also electricity demand is never constant. Therefore, using an energy storage technology into renewable energy generating system is important. There are many different technologies available for storing energy; they come in all forms of energy such as mechanical, chemical, and thermal.

4. The main drivers of RE-DG growth

In the current electricity grid structure, electricity is produced in huge bulky power stations and brought to consumers via current carrying equipments such as transformer, transmission line, and distribution network. Current electricity supply is associated with high cost of generation, operation, maintenance as well as considerable power losses. Because of the advantages that RE-DG has, we can observe gradual growth in using RE-DG in the electricity networks.

There are many drivers behind growth of RE-DG. These drivers include:

Environmental driver of RE-DG: Currently a large portion of electricity, worldwide, is generated in Giga-watts power stations using fossil energy technologies. These are known as high-carbon technologies and are considered as source of greenhouse emissions. Using RE-DG allow us to gradually move from high to low carbon technologies.

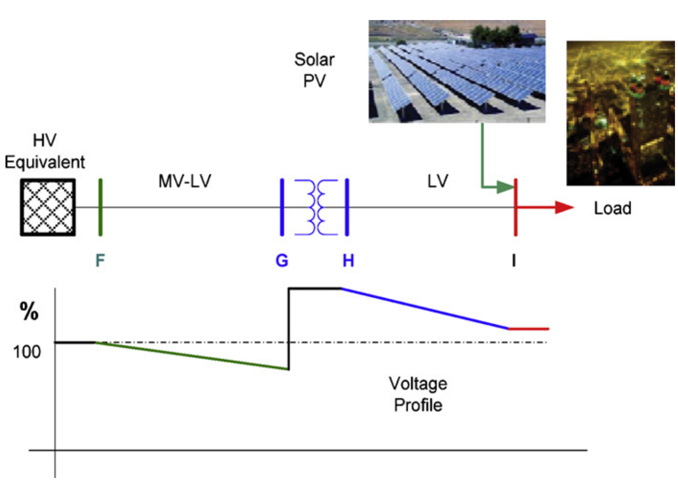

Fig. 8. Voltage profile at LV side when RE is connected at load side.

Economical driver of RE-DG: Electricity generated in central power stations are delivered to the customers and load centres through high voltage transmission lines. Transmission lines are expensive component of a power system. And also a fraction of electric power supplied by power stations is lost in the transmission lines before being delivered to the users. As RE-DG are connected to the distribution network and are closer to the load, therefore, using RE-DG eliminates need for transmission line, which results in saving costs and minimizing power loss.

RE-DG improves power quality and reliability: Closeness of RE-DG to load centres makes easier for operators to control the system voltage. And also RE-DG will be able to reduce number of customers without power in case of power outage, if the RE-DG is allowed and able to stay.

RE-DG protects non-renewable and limited sources: Some of the sources currently used for electricity generation are non-renewable sources with limited reserve volume. RE-DG uses renewable sources, therefore protect and extend the life of the limited sources.

5. Technical issues with increasing use of RE-DG

There are some technical issues that limit usage of RE-DG on a power system. These issues include:

Reliability issues: The amount of power that a renewable source of energy such as solar and wind can produce depends on availability of sun and wind. As sun radiation and wind speed are never constant, therefore the output power of a solar energy system or a wind power will never be constant. Hence, high penetration of RE-DG into a power network can result in risk of making the entire network less reliable.

Power quality issues: Power quality is an important factor of a power system particularly these days that new electrical devices are sensitive to voltage variation [9]. Power quality of a power system is measured by level of voltage variations (over-voltage and under-voltage), level of frequency variation and harmonics. Voltage fluctuation is a challenging issue particularly in high penetration level of RE-DG. This issue needs to be seriously considered in integrating intermittent sources. Voltage fluctuation is noticeable when a large wind turbine is connected to a weak distribution network particularly during starting and stopping process [10]. There are many other issues such as harmonics, noise level, etc. in relation to increasing use of RE-DG. These issues are beyond scope of this paper.

6. Important location of RE-DG and its impact on the system voltage

With the growth in distributed power generation, the power flow becomes more complicated. Many large renewable plants feed directly into the medium voltage (MV) networks and many wind turbines even to the low voltage (LV) networks. Only when a large amount of PV power is fed into the network, the HV network must be considered. In such cases, the range of the automatic tap changers of the HV/MV transformers would need to be reviewed [10].

Choosing suitable connecting point of RE-DG to the grid is an important task of the design process. Connecting RE-DG at load side or transformer side will cause power variation and consequently this variation has immediate impact on system voltage. Variation of power at low-voltage side results in the undesirable voltage variation. Depending on penetration level, RE-DG might cause voltage increase particularly at low load conditions. Therefore, automatic voltage controller at low voltage side must

carefully control the voltage. Fig. 4 shows voltage profile in a simplified power network at all levels. The power direction through a transformer would always be from the higher voltage level to the lower voltage level. The only exceptions from this are the power plant step-up transformers. Fig. 5 shows voltage profile at LV side of a grid without RE-DG. Fig. 6 shows effect of connecting point of RE-DG on voltage profile. Fig. 7 shows voltage profile with voltage controller at transmission side. Fig. 8 shows possible over-voltage when RE-DG is connected at load side.

7. Conclusions

This paper has reviewed the potential benefits of RE-DG in the future grid and its possible connecting to the grid. This paper has reviewed the drivers behind increasing use of RE-DG as well as technical challenges associated with high penetration of RE-DG. Location RE-DG is important from operation point of view of the grid. This paper has also reviewed the important effect of RE-DG connecting point on the system voltage.

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